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Neutron Activation of NIF Final Optics Assemblies

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Abstract. Analyses were performed to characterize the radiation field in the vicinity of the Final Optics Assemblies (FOAs) at the National Ignition Facility (NIF) due to neutron activation following Deuterium-Deuterium (DD), Tritium-Hydrogen-Deuterium (THD), and Deuterium-Tritium (DT) shots associated with different phases of the NIF operations. The activation of the structural components of the FOAs produces one of the larger sources of gamma radiation and is a key factor in determining the stay out time between shots to ensure worker protection. This study provides estimates of effective dose rates in the vicinity of a single FOA and concludes that the DD and THD targets produce acceptable dose rates within 10 minutes following a shot while about 6-days of stay out time is suggested following DT shots. Studies are ongoing to determine the combined effects of multiple FOAs and other components present in the Target Bay on stay-out time and worker dose.

1. Introduction

Construction of the National Ignition Facility (NIF) has been completed and early phase experiments leading to eventual controlled self-sustaining nuclear fusion energy gain have commenced at the facility. The neutrons generated by these experiments activate various components and structures present in the facility. A good understanding of the level of residual radiation present at various locations in the facility is important in determining the stay out time between shots to ensure worker protection.

Final Optics Assemblies (FOAs) provide beam conditioning, frequency conversion, focusing, and debris protection in a compact module. There are four optics modules per FOA with forty eight FOAs attached to the target chamber wall. They focus the 192 laser beams to the target chamber center. Since they are in direct line of sight of the target, the FOAs experience some of the highest neutron fluences outside the target chamber. This study will focus on the activation of the large structural components in the FOA and estimate the effective dose rates in the vicinity of a single FOA.

2. Computational Model

The radiation transport code, MCNP [1], was used to obtain the neutron flux spectra in various structural components of the FOA. These fluxes were then used to activate these components using the activation code, ALARA [2]. The gamma sources from ALARA for the various structural components of the FOA were then used in a second MCNP calculation to obtain effective contact and 1-ft dose rates from each of these components. ICRP-74 [3] flux-to-dose rate conversion factors were used to obtain the dose rate estimates.

Targets representing different phases of NIF operation were used in the models. For the Deuterium-Deuterium (DD) shots a yield of 1×10^{13} neutrons/shot was used with a shot schedule of 4 shots per day

for 50 days. The DD source spectrum used for the neutron calculations was 99% 2.45 MeV and 1% 14.1 MeV. The Tritium-Hydrogen-Deuterium (THD) shot was assumed to yield 2×10^{14} neutrons/shot with a shot schedule of 2 shots per day for 50 days. A full THD neutron source spectrum based on 2% deuterium content was used for the calculations. The Deuterium-Tritium (DT) shot was assumed to yield 7.4×10^{18} neutrons per shot with a shot schedule of 60 shots per year with a six day interval between shots. A full DT source spectrum with a 14.1 MeV peak was used in the calculations.

A detailed model of the FOA (Figure 1) was used in the MCNP neutron flux spectrum calculations. All 48 FOAs were included in this model that contained sufficient detail of the target chamber walls, the floors and structural columns inside the Target Bay (TB) (Figure 2). The MCNP gamma calculation used a simplified model of the FOA that was voided out and divided into eight axial regions each with its own gamma source. Thus, having no self shielding, this model yielded conservative estimates of the dose rates.
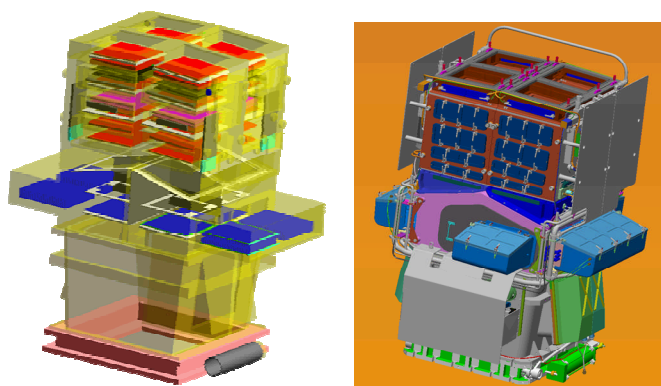

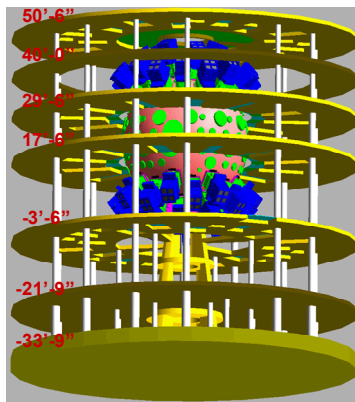**Figure 1**. Final Optics Assembly: MCNP model (left), CAD model (right)

Figure 2. MCNP model of the Target Bay

3. Effective Dose Rates from an FOA

The decay times shown for the three target types are after the last shot in a shot sequence and account for isotopes that may accumulate over the time span of the shot schedule. The tables presented for each target type contain both the contact dose rate and the dose rate at 1 ft from the region of the FOA that produced the bounding value. It must be noted that in the cases of the THD and DT shots, different regions of the FOA were bounding at contact and 1 ft away.

3.1. Dose Rates from DD Shots

The main contribution to the dose rate in the short term comes from ^{28}Al with the longer term contribution from ^{56}Mn and ^{24}Na. Table 1 presents the results from DD shots. These dose rates are negligible at 10 minutes after the last shot.

Table 1. Effective Dose Rates from DD Shots

Time after last shot (minutes)	Contact Dose Rate (mrem/h)	1-ft Dose Rate (mrem/h)
10	2.39E-02	1.95E-02
30	2.06E-03	1.77e-03
60	1.52E-03	1.23E-03
360	6.24E-04	6.03E-04

3.2. Dose Rates from THD Shots

The main contribution to the dose rate in the short term comes from ^{28}Al, ^{24}Na, and ^{27}Mg. The longer term contributions come mainly from ^{24}Na and ^{56}Mn. Effective dose rates at 10 minutes after the last shot are at acceptable levels of approximately 1 mrem/h. Table 2 presents the results from the THD shots.

Table 2. Effective Dose Rates from THD Shots

Time after last shot (minutes)	Contact Dose Rate (mrem/h)	1-ft Dose Rate (mrem/h)
10	1.38E+00	6.21E-01
30	3.43E-01	1.31E-01
60	1.74E-01	6.64E-02
720	8.56E-02	3.03E-02

3.3. Dose Rates from DT Shots

The DT yield shots correspond to 20MJ of energy and produce the highest amount of activation. Table 3 presents the results at decay times after the last of the 60 shots. The dose rate at 6 days after the last shot on contact with the FOA is approximately 6 mrem/h and over 2 mrem/h at a distance of 1 ft. The main contribution to the dose rates come from ^{24}Na, ^{54}Mn, and ^{58}Co.

Table 3. Effective Dose Rates from DT Shots

Time after last shot	Contact Dose Rate (mrem/h)	1-ft Dose Rate (mrem/h)
1h	4.96E+03	1.99E+03
12h	2.19E+03	8.03E+02
1d	1.23E+03	4.51E+02
6d	5.82E+00	2.35E+00
10d	1.10E+00	6.02E-01

4. Conclusions

Structural components of the FOAs produce dose rates that are low enough to allow entry into the TB at 10 minutes after DD and THD shots. However, more realistic entry times (for other reasons) will be closer to an hour after the shots making the radiation levels even lower. For the DT shots, a stay-out time of days will allow radiation levels to reach acceptable values that ensure worker safety.

This study examined the contribution of a single FOA to the radiation field after shots with different targets. In reality, the radiation levels in the TB will be the cumulative value from multiple FOAs and other components and structures present. Studies are being conducted to estimate these cumulative radiation levels at various locations within the TB. Preliminary results indicate that for the most part the FOAs would contribute the largest fraction to the dose rate on the two floors where they are present.

References

[1]   X-5 Monte Carlo Team, "*MCNP - A General Monte Carlo N-Particle Transport Code, Version 5,*" Los Alamos National Laboratory, LA-UR-03-1987 (2005).

[2]   P. Wilson and D. Henderson, *"ALARA: Analytic and Laplacian Adaptive Radioactivity Analysis code,"* University of Wisconsin, UWFDM-1070 (1998)

[3]   International Commission on Radiological Protection, *"ICRP Publication 74: conversion coefficients for use in radiological protection against external radiation,"* Pergamon press (1997).